PROJECT TITLE

RAINFALL INTERCEPTION IN AN AFFORESTED AREA: CHUNGA CATCHMENT AREA

BY

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This research report was submitted on 27th June, 1988 as part of the physical Geography single major programme for the award of a Bachelor of Arts degree at the University of Zambia, Lusaka Campus.

DECLARATION

I, INESS SIMUUNZA, wish to declare that this project has been composed by me and that all the work contained in this report is my own. All maps and diagrams were drawn by me. All work and/ or ideas which are not mine have been dully acknowledged and the project has not been previously submitted for an academic award.

SIGNED: INESS SIMUUNZA

ABSTRACT

An interception study was conducted in an exotic vegetation of Eucalyptus trees to unravell how componets of the interception process are distributed and what factors affect them.

Rainfall was measured at an open site and under four samples of Eucalyptus trees (Grandis). Between 67 and 77 percent of the rain penetrated each of the canopies with the average being 71 percent. Stemflow averaged 14.8 and ranged from 13.5 to 16.6 percent. Interception loss averaged 42.5 with a range of 39 to 46 percent.

The lower penetrations observed in the study were attributed to the thickness of the tree canopies for the four samples. Stemflow values were larger than what most studies have recorded and this was attributed to the smoothness of the barks, the age of the trees and consequently the distance taken for the stemflow to reach the collector. Interception loss was found to be higher because of the age of the trees.

The variations of the components between samples were associated mainly with aggregate amount and intensity of rainfall and to a loss extent vegetational characteristics.

DEDICATION

To my family who I have always
Loved.

ACKNOWLEDGEMENTS

The completion of this study has been made possible by many people. It is my greatest pleasure to acknowledge the assistance I received.
Firstly my thanks go to Mr. A. C. Chipanshi, my Lecturer in Geography who was my project supervisor who helped me to frame the topic of the project, provided me with some references and whose instruction, encouragement, critical comments and patience has seen the completion of this project.

I also wish to acknowledge help rendered to me from staff of the Forestry Department at Lusaka especially Mr. Mwila who helped me to collect the data for the project.

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INESS SIMUUNZA.

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CHAPTER 1

INTRODUCTION

It has long been realized that interception is of great importance in soil and water resource conservation and management particularly in catchment areas. It is important to know how much rainfal a tree species intercepts before it is chosen for catchment area protection. This realization was among other factors that led Townsey (1957) to carry out an interception study on Wellington mountain in Tasmania in which he found out that precipitation intercepted by trees constituted an appreciable fraction of the total precipitation.

Water demands by industry and by populations which are constantly rising and the increasing demand for information on rainfal and water expenditure in catchment areas have attracted even more investigators on the subject. Most of these studies have taken the budgetary approach either for a stand or single tree in order to examine the effects of vegetation and rainfall characteristics. Noteable studies include those by Aranda and Coutts (1963), Robins (1974) and Hutchinson and Roberts (1981). These studies nevertheless, were conducted in temperate areas so that there is paucity of information on the subject in the tropics. A few studies that have been reported from the tropics such as Freise (1936) quoted in Geiger (1965) seem to lag behind in terms of the research effort compared to temperate ones. It is in the light of this realization that this study was undertaken.

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PURPOSE AND OBJECTIVES OF STUDY

The purpose of the study is to investigate the rainfall characteristics in the study area. These include aggregate amounts, time interval between occurance and rainfall intensity. Vegetation characteristics include plant species and maturity as well as stand density. The study hopes to find out what bearing rainfall and vegetation characteristics have on the inter-ception components, that is inter-ception loss, throughfall and stemflow.

The objectives of the study are thus two-fold:-

(1) To find out how an afferested area expends precepitation and

(2) To find out the factors affecting interception in an afforested area.

DEFINITION OF TERMS:

Terms related to the interception process as used in this study are defined below:-

(b) Interception Loss

This is the portion of the precipitation retained by the vegetation and is either absorbed by it or is returned to the atmosphere by evaporation.

(c) Throughfall

Throughfall which in this paper will be referred to interchangeably with percentage penetration has been defined as the portion of rainfall that reaches the ground directly through the vegetation canopy and through openings and as drip from leaves and twigs.

(d) Stemflow

This is defined as that portion of the intercepted rainfall that trickles along twigs and branches and finally down the main trunk to the ground surface.

CHAPTER 2

LITERATURE REVIEW

FEATURES OF INTERCEPTION

Studies of the distribution of rainfall in vegetated areas have shown that when it begins to rain much of the water is intercepted in leaf and stem depressions or held by surface tension forces as drops on the leaves, bark surfaces and edges. One way of appreciating the interception process is to look at the shelter effect of a tree during a rain stor as suggested by Penman (1969). At the beginning of a rainstor, protection is almost complete and the ground beneath the tree remains dry, but with passage of time drops of water begin to fall through the canopy. The drops increase is frequency and size until such a time when the tree provides no protection at all. Eventually, drops of water continue to fall from the leaves after rainfall has ceased. This observation depends on the nature of rainfall.

The simple illustration above affords a clear indication both of the sequence of events and of the main features of interception. At the beginning of the rainstor much of the water is caught in the tree canopy and as a result the ground beneath the tree remains dry. But as the rain continues at a greater rate than that of evaporation the drops stored on various parts of the tree canopy increases in size so that the surface tension forces are (over- come) and the drops move from leaf to leaf forming still larger drops. Delfs (1967) found out that the lag time, which is the time taken for the rain to penetrate the tree canopy from the time it started to rain may last for several hours with light rain. Eventually all parts of the tree will reach maximum water storage capacity and water will begin moving out of the tree as throughfall and stemflow. Storage capacity which is the term used to describe the amount of precipitation that can be taken up by the crown before water penetrates the forest floor was found by Delfs (1967) to range from 1 to 3mm in Spruce and Beech forests. Aranda and Coutts (1963) found it to be at least 2 mm in conifers.

Penman's illustration above shows that interception loss from vegetation is greatest at the beginning of a storm and reduces with time. This reflects the interaction of the main factors that affect it. These factors are categorized in two groups as interception capacity of vegetation cover and meteorological conditions.

VEGETATION CHARACTERISTICS

The interception capacity of vegetation is a function of vegetation structure and morphology . These in turn depend upon composition, age and density of stands.

The effect of species on the difference of interception has been particularly noticeable between broad- leaved and coniferous trees. Many studies have shown that coniferous trees intercept more rainfall than broad-leaved or deciduous trees in full leaf. This is illustrated in Table 2.1. This fact has been verified by many investigations. Aranda and Coutts(1963) found interception of about 48 percent and 3 percent in coniferous and deciduous trees respectively. Delfs (1967) in a 5-year period found a mean interception of 25.8 percentage for Spruce and 7.6 percent for beech. The low value for beech was a result of the smaller storage capacity of the crown and the extremely small amount of moisture required for wetting the surfaces of the stem and the branches. Therefore, although the deciduous canopy is denser than that of conifers, its broad leaf promotes drop coalescence and flow.

TABLE 2.1 RAINFALL INTERCEPTION RATES AS A PERCENTAGE OF PRECIPITATION FOR SEVERAL FOREST TYPES

FOREST TYPE	GROSS INTERCEPTION		STEMFLOW		NET INTERCEPTION	
	With Leaves	Without Leaves	With Leaves	Without Leaves	With Leaves	Withou Leaves
Northern Hard Woods	20	17	5	10	15	7
Aspen-birch	15	12	5	8	10	4
White- Pine	80	-	4	-	26	-
Spruce fir	35	-	3	-	32	-
HemLock	30	-	2	-	28	-
Red Pine	32	-	3	-	29	-

<u>SOURCE</u>: Geiger (1965) The climate near the Ground uderline Harvard University Press, Cambridge, Massachusetts London, England.

Where as the separate needles of conifers tend to retain individual raindrops and do not promote flow (Geiger 1965).

Table 2.1 also shows that unlike coniferous trees deciduous species display seasonal variation in interception capacity and loss in response to changes in leaf cover. Ward (1967) has observed that the total leaf area per unit ground area of grasses and herbs and of closed canopy forests are similar. It is for this reason that the interception capacities and losses during the season of maximum development have been suggested to be of similar magnitude. However it is difficult to measure interception in grassy type of vegetation and there is very little research on such vegetation covers.

Age has an important influence on the amount of interceptions. Delfs (1967) found the mean interception by Norway Spruce over several years to be 36 percent in an 80-year old stand; 28 percent in a 60 - year stand, 21 percent in a 30 - year old thicket and 11 percent in a 15 - year-old regeneration. He attributed this increase with age to the greater crown length and denser foliage in the older stands.

The effect of spacing on interception determines the possibility of influencing water discharge by thinnings and fellings. Delfs (1967) in his study above found that a light opening in the canopy does not reduce interception. He found the interception in a dense spruce pole stand to be 30 percent, that in a light-thinned stand to be 31 percent and 22 percent in a small opening. He attributed the unexpected result in the opening to wind action which might have prevented some of the rainfall from reaching the ground.

METEOROLOGICAL CONDITIONS

The meteorological conditions affecting interceptions vary in importance with rainfall durations. For short period storms in which interception capacity is not filled, all the precipitation may be evaporated.

In such a case the interception loss is limited by water supply and will vary with precipitation. Ward (1967) observed that even during rainfall some water may still be lost by evaporation from the leaf surfaces so that even when initial interception capacity has been filled; there is some further fairly constant rentention of water to make good thus evaporation loss. Kittredge (1948) found out that when evaporation in the open was taken as 100 percent it was 83 percent in pine; 69 percent in pinus Lamberiana and 17 percent in a dense mature stand of Abies concolour.

Wind effect on the interception process will depend on development of the canopy. The density and wind speed has an accelerating effect on the evaporation processes in that it can constantly replace saturated air. Ward (1967) has said that other conditions remaining constant; evaporation will increase with wind speed, so that during long period rain storms the interception loss is greater in windy than in calm conditions. coutts and Aranda (1963) reported similar findings in their study of an afforested area near Aberdeenshire. The wind effect nevertheless depends on the length of a rainstorm. During a short duration storm wind speed can considerably reduce the interception capacity of a tree by agitating the foliage and causing premature throughfall. Thus, generally speaking wind increases the total interception loss for a long duration storm and decreases it for a short duration one.

From the above it is implied that the duration of a rainfall is a secondary factor in that it influences interception by determining the balance between the reduced storage of water on the vegetation surfaces on one hand and increased evaporation losses on the other. Data collected by Aranda and Coutts (1963) and Geiger (1965) showed that interception loss increased with the duration of rainfall, but only gradually so that the relative importance of interception decreases with time.

Although Ward (1967) has said that rainfall amount is of less significance, Aranda and Coutts (1963) noted its importance in relation to its interacting effects with other fators such as duration and that interception loss tends to decrease as the amount of rainfall increases. Unlike rainfall amount, rainfall intensity has been found to be of greater influence on interception in that it tends to increase as intensity decreases for long duration storms. Delfs (1967) found that in heavy thunderstorm during which 74.6 mm of rain fell within $3\frac{1}{2}$ hours only 2 percent was intercepted while the interception was 25 percent from a continuous rain with 70.5mm rainfall over 50 hours.

Rainfall frequency has been noted to be of considerable significance than either duration or amount of rainfall. Aranda and Coutts(1963) and Geiger (1965) showed that where evaporation rates were high between showers interception capacity was at a maximum when each shower began. In these circumstances little of the rain would reach the ground and interception losses might exceed 90 percent of the precipitation above the vegetation cover. When the total of precipitation is made of similar short showers seperated by periods of clear weather; interception may be as much as 35 to 50 percent of the total. But if these same amounts of rainfall occur during prolonged falls on vegetation which is almost continuously wetted, total interception loses will be lower.

It is evident therefore; from the way the forest behaves toward falling rain that the rain intensity, duration, amount and variation with time are of vital importance depending on the nature of the vegetation. Ovington(1954) quoted in Geiger (1965) stated that interception could range from 6 to 93 percent depending on the character of the rain and vegetation stand. He also found out that interception for a single stand would be great in proportion to rainfall when the rain was light, of short duration, and would be small for persistent rain or heavy showers over a wide area.

Delfs (1967) found interception to range from 7.6 to 25.9 percent in Beech and Norway spruce. Zinke (1967) has compiled interception data for many species in the United States of America and has found a range of 3 to48 percent. Kittredge (1948) has said that an average a forest could return as much as 30 percent of the total precipitation directly to the atmosphere as interception loss for light rain of short duration.

FEATURES OF STEMFLOW

Stemflow is usually very small and almost an inisignificant contributor in the water regime .Eidmann (1967) found summer stemflow to be 0.7 percent in a 65-year old Spruce. Studies by Kittredge (1948) Aranda and Coutts (1963) and Delfs (1967) have shown that normally stemflow begins several hours after the beginning of the rainfall. A certain amount of rain is necessary to wet the foliage, branches and stems before flow is possible. This depends on the age of the tree. Delfs (1967) found that a longer period was required to wet the stems of a mature timber than on pole stands. Geiger (1965) also verified this fact by reporting stemflow of more than 3 percent in a young stand compared to 0.8 percent in the old stand.

Stemflow has also been found to depend largely on the roughness of the bark. Delfs (1967) found the stemflow of beech to play a relatively more important role as a result of its smooth bark compared to that of Spruce. The mean s stemflow measured by him in saverland, United States ranged between 16.6 and 18.7 percent compared to only 0.7 percent for spruce. Delfs also found that there was a correlation between stemflow and stem diameter. If stemflow was expressed as a percentage of rainfall; the stems with the smallest diameter exhibited the greatest amount of stemflow.

He also found that stemflow began when rainfall amount was 2mm.

On the whole researchers have reported a relatively small proportion of precipitation for stemflow. Carlisle, Brown and White (1967) obtained stemflow of 3.6 percent and Delfs (1967) as small as 0.7 percent in Spruce. However, other obtained large proportions. Hoover, Olson and Greene (1953) quoted by Aranda and Coutts (1963) obtained stemflow of up to 20 percent in loblolly plantations Delfs (1967) recorded 16.6 percent in beech stands. All these differences in stemflow values indicate that stemflow may vary depending on the tree species, age and bark texture.

FEATURES OF THROUGHFALL

Throughfall is an important component of interception which is usually irregularly distributed around a tree. Hoppe (1896) quoted by Geiger (1965) showed that throughfall increases with increasing distance from the stem at the individual trees. He found that it was 55 percent near the stems and 76 percent at the borders of the crowns Throughfall has been found by Geiger (1965) to be dependent upon the age of the stand. A study done in an old fit. Stand by Hoppe, Delfs and others in 1948 and 1958 quoted in Geiger (1965) indicated that the relations between interception and throughfall was a function of amount of precipitation and age. Younger stands allowed more rain through the forest floor than old stands as is illustrated in figure 2.1.

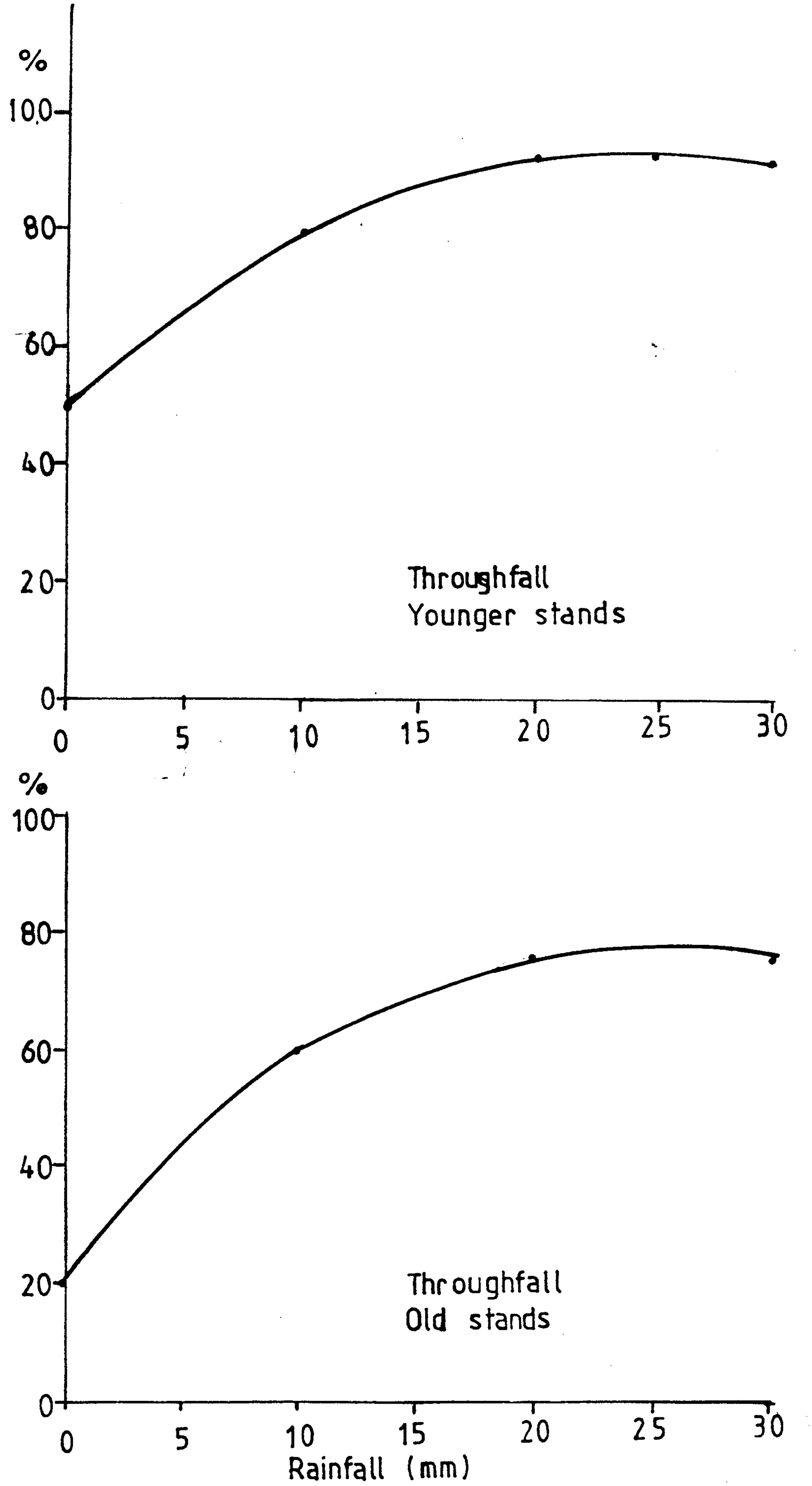

Fig. 2.1 Interception in Fir stands as a function of Amount of Rainfall. (Enlarged after Geiger 1965).

Throughfall has been found to average 85.9 percent with a range of 77.4 to 93.8 percent by Rogerson (1967) in pole-sized loblolly pine. Aranda and Coutts (1963) obtained throughfall ranging from 40 to 84 percent of the total rainfall. The variation in throughfall has been attributed to drip effects and to differences in rainfall and vegetation characteristics by Geiger (1965) and Aranda and Coutts (1963) respectively.

Most of the studies cited above have taken the budgetary approach which has been emphasized by Geiger (1965). His main argument being that if less water reached the ground in a wooded area its contribution toward water supply would be smaller than from open country. It has been observed however, that there is very little information available on the topic within the tropics. Freise (1936) quoted by Geige (1965) conducted such a study in the subtropical forest of Brazil. Of the total precipitation 20 percent evaporated in the crown space, 28 percent reached the ground as stemflow and 34 percent dropped through the remaining 18 percent disappeared into the bark and hollow stem and by further evaporation.

It is in the light of this realization and the disparities in the results of too few studies that initiated a need to extend studies of this nature to Zambia. Pereira (1967) has shown that hydrological studies in Zambia started in the colonial period but focussed mainly on the major rivers. Later attempts to begin forest hydrology research were made due to political pressure arising from the disappearance of vegetation cover on the major watersheds.

Presently this new thought and the concern for proper utilization of water resources and conservation has become a matter of fact and rather unexpected in a Young but fast growing developing nation whose water demands by industry and by a rapidly increasing population are constantly rising. Therefore, information on rainfall and water expenditure, particularly in catchment areas is of great importance. This study therefore, hopes to shed more light on how rainfall is distributed in a forest in the hope that this will help plan effective policies in soil and watershed protection and management. The study intends to shed more light on the subject in a tropical setting in relation to what has been observed in temperate areas.

CHAPTER 3
DESCRIPTION OF STUDY AREA

LOCATION OF SITE AND VEGETATION COVER

The work was done in the Lusaka North Plantation which is situated to the north of Lusaka about 4 kilometres from the Central Business District along the Great North Road. The plantation was started in 1957 and has Six compartments one of which was chosen for the study.

The site is a well established plantation of Eucalyptus trees (Eucalyptus Grandis) which are about 6 years and 3.05 metres apart. The trees are 6 metres in height and 0.19 metres in breadth. The trunks are smooth. The stand density was estimated at 34,750 trees per hectare. The site provided security for field equipment and a rainfall station which was taken as the open site from which rainfall data for the study were obtained. The raingauge in this site was located on a termite mound with no trees or shrubs except grass growing on it. This was located to the east of the study plot. Figure 3.1 shows the location of the study area.

CLIMATE

Lusaka like any other place in Zambia experiences a tropical climate although it is modified by altitude and distance from the sea. Four seasons are significant; The rainy season running from November to March, the post rains warm season from April to June, the cold dry season from June to August and the hot dry season which runs from September to November.

The Rainy Season

This is the period during which the study was conducted

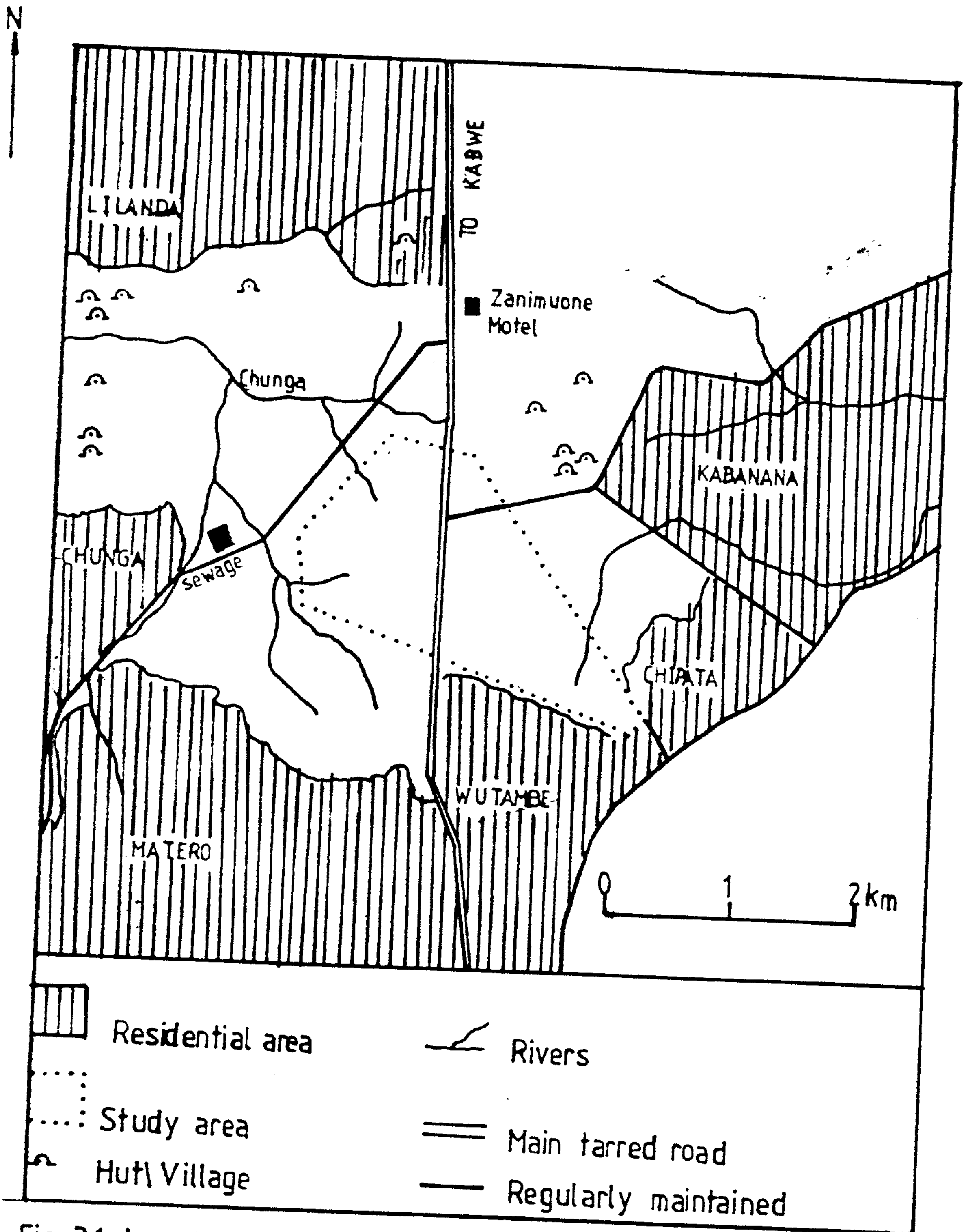

Fig. 3.1 Location of Lusaka North Plantation.

Traced from map sheet $15A_4$ Lusaka 1986 commencing on 28th November, 1987 to 21st March, 1988.

The rainy season at Lusaka arrives with a number of circulation patterns which influence the region by introducing advected air which is both moist, unstable and convergent. Three circulation systems influence the climate of Lusaka during this time. These include the Angolan low, the Zaire Air boundary and the inter-tropical convergence zone. The annual rainfall of Lusaka averages to 803 mm and 95 percent of this falls in the five- month rainy season. Rainfall is quite reliable although there are daily and divrnal variations. Wind speeds are less on rainy days but wind direction usually presents a complex pattern. Maximum air temperatures are consistently lower on rainy days than other days by an average of 1.4°c due to increased cloudness and lower incident solar radiation. The mean rainfall on rainy days at Lusaka is 9.0mm although there are wide daily variations.

Temperature

Lusaka temperatures are moderate. The average maximum for the warmest month (October) is 31.2°c and the average minimum for the coldest month (July)is 9.6°c. The highest temperature recorded at the city airport is 38.2°c and the lowest 3.9°c. Frost is said to occur in low - lying valleys into which colder air drains. Lusaka is reported to be a 'windy city' with persistent winds blowing from the east being the most persistent. Table 3.1 gives a summary of selected climate means for Lusaka.

VEGETATION

The natural vegetation for Lusaka is the dry-deciduous woodland called Miombo . This is most prevalent in the Southern and south-Eastern parts of the city. To the West and South-West of the city is an open savanna woodland known as Munga. This is also found in a narrow tongue to the North of Lusaka between Chongwe and Mwembeshi river.

There are dambos too although these are poorly developed. These are streamless but usually water logged during the rain season. In lower reaches at rivers such as the southe west towards Kafue river extensive riverine and floodplain grasslands exist as well as evergreen riparian woodlands.

Within the built up area of Lusaka and in the immediate environs of the city, little of the natural vegetation survives. Most of the area was cleared for European Agriculture and also provide timber products, building material, firewood and charcoal for the city. Concern over this paucity of woodland led to the establishment of forest reserve such as the study area to the North, East and South-East of the city. In these forest reserves exotics have been introduced with Eucalyptus being dominant.

Vacant lands are considerable on the immediate periphery of the city and are intensely cultivated for maize and vegetable

DRAINAGE

Generally Lusaka has a radial drainage pattern which reflects the underlying rock type of the city. The Chunga which is a tributory of the Mwembeshi has its source in the Norther part of Lusaka and drains the area which is underlain mainly by schist with a few quartzite astride. The great North Road in the viscinity of the Independence stadium. The study site separates two drainage systems; the Chunga flowing westward and the Ngwerere flowing eastwards. Therefore the site occupies a strategic location as far as water conservation and water shed protection is concerned. Thus quantifying a part of the hydrological component is a first step towards understanding redistribution and availability of surface water in a predominantly 'dry' area.

The plantation provides vegetation cover which increases infiltration by retarding surface flow, so allowing more time for water to enter the soil and shielding the soil surface from the direct impact of raindrops which reduces compaction. The root system development also increases the permeability of the surface layers. Further more water sinking into the soil under vegetation cover, is in excess of overland flow because water dropping to the ground surface is of less intensity and is easily absorbed by the soil. This adds more water to the soil moisture reserves than for areas without vegetation cover. This threfore ensures a continous supply of water to the two water systems sharing the water-shed.

The south-western quarter of Lusaka is drained by the Chilongola, Cheva and Mungu which are tributaries of the Kafue. South of the city only Chilongolo is the stream of significance on the water less surface of the plateau. An extensive area in the central plateau of the city is almost devoid of surface drainage. This is because the Limestone underlying the area allows the rainfall to enter it with relative ease. To the south-east is the Funswe which is confluent with the Kafue. To the North-east are the Chalimbana and the Ngwerere which are both tributaries of the Chongwe which in turn flows into the Zambezi. Figure 3.2 provides a summary of the hydrology of Lusaka ~~of Lusaka~~ noted above.

	TEMPERATURE (OC)		RAINFALL (MM)	WINDSPEED (NOTS)
	Mean Max.	Mean Min.	NIL	
JULY	22.7	19.6	Min.	7.7
AUGUST	25.4	11.7	NIL	8.5
SEPTEMBER	28.9	14.7	1	8.9
OCTOBER	31.2	17.8	16	7.6
NOVEMBER	28.7	17.8	82	5.7
DECEMBER	26.5	17.3	1.94	4.7
JANUARY	25.8	17.2	222	4.1
FEBRUARY	25.8	17.1	179	3.7
MARCH	26.1	16.3	88	6.3
APRIL	26.3	14.0	15	7.2
MAY	24.6	12.0	5	7.1
JUNE	22.8	10.2	1	7.8
YEA	26.2	14.7	803	6.6

Table 3.1 Selected climate means for Lusaka (Based on records taken at the Lusaka City Airport) 1941- 1966

Copied from Tyrell (1986) and Williams (1983)

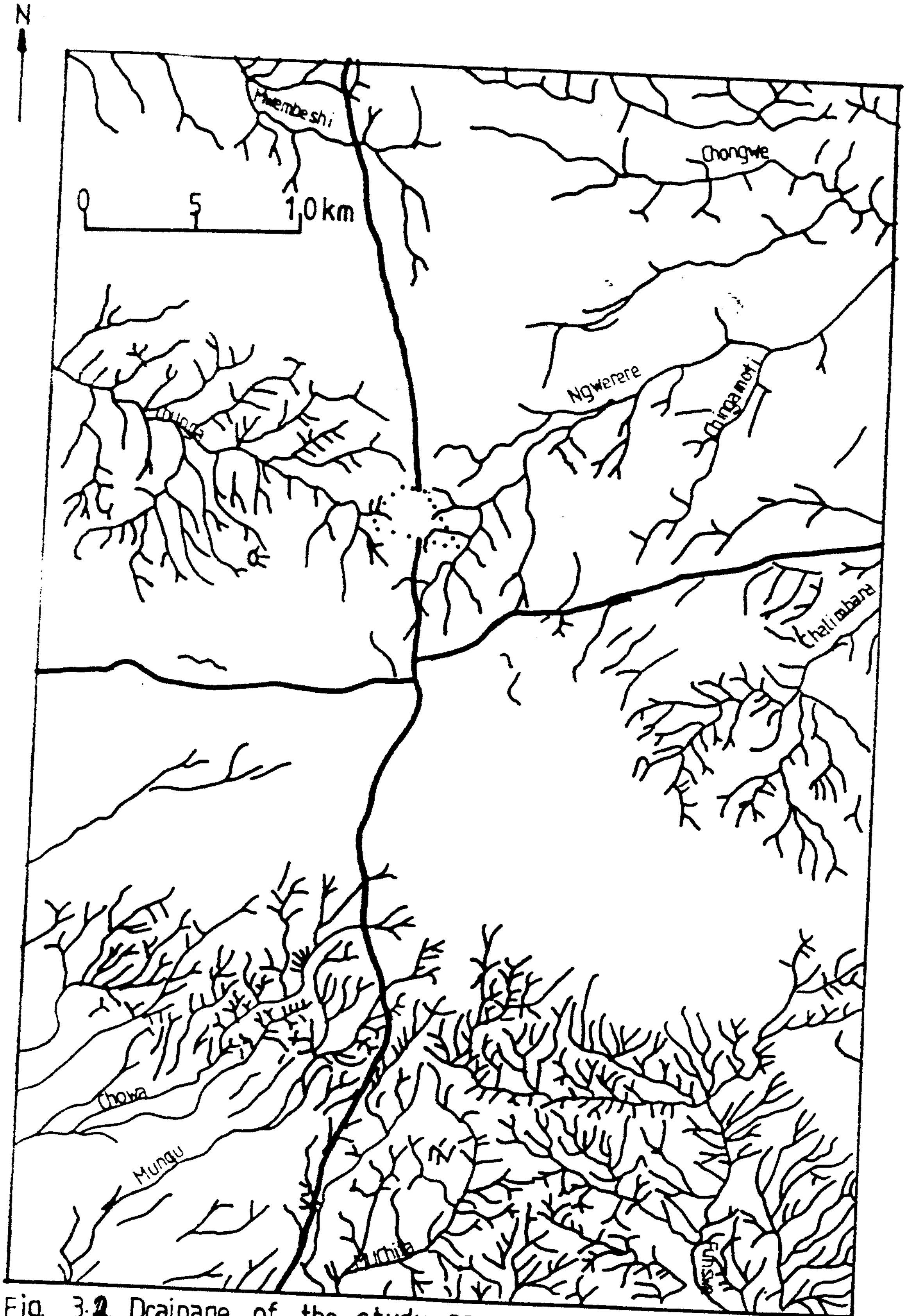

Fig. 3.2 Drainage of the study area
Traced from Williams G.J (1986) Lusaka and its Environs: A Geographical study of a Planned City in Tropical Africa. Z G A. Lusaka.

CHAPTER 4

METHODS OF DATA COLLECTION AND ANALYSIS
MEASUREMENT OF METEOROLOGICAL ELEMENTS

Rainfall amounts

Rainfal amounts in the open site was measured using the standard raingauge as described by Ward (1967). The gauge used was a non-recording one belonging to the Lusaka North Meteorological station. This gauge monitored the total rainfall input into the plantation. The values from it were the basis for the calculation of the percentage penetration, stemflow and interception loss.

Despite the fact that a standard reingauge was used there are unvoidable difficulties inherent in point measurements of precipitation. These include splash- in and out effects evaporation, losses in wetting the gauge surfaces and in accuracies due to improper levelling of the gauge criffice. These errors and their causes have been summarised by Ward (1967) and corbett (1967). The raingauge at the study site gave reasonable readings which compared well with those from both non automatic and automatic gauges of a nearby rainfall station at the University of Zambia. Thus potential errors were insignificant.

Rainfall Intensity

A meteorological self-recording rain gauge from the University of Zambia meteorological station was used. This was the nearest station with self-recording instruments. It is about 8 kilometres from the study site. Charts from this gauge were used to estimate rainfall intensities.

Wind Speed

Wind speeds were also obtained from the University of Zambia meteorological station. These speeds were taken on 24 hours basis. A weakness in this data could have been that the conditions at the study site might not have been exactly the sam as those over the University of Zambia. But this could not be avoided since it was the nearest station with self-recording instruments.

INTERCEPTION COMPONENTS

Throughfall

Plastic funnels of about 12.5 centimetres in diameter with a vertical flange fitted to 750 ml. Cooking oil bottles were used as improvised raingauges to monitor throughfall because acquisition of standard rain gauges was not possible. The bottles were put into used paint tins of about 30 centimetres in height and whose tins corresponded to the diameter of the funnels. These tins served as collection cans in case of an overflow during exceptionally heavy falls. In such cases both the can and the bottle were removed and emptied in a measuring cylinder.

Taking into consideration the cost of the material for the gauges and the area under investigation; four imprevised rain-gauges were installed within the study plot. Individual readings were taken from each gauge under the tree canopy. Then average readings were used in order to minimize sampling error. Installation of these gauges was done at ground level. The paint tins were slightly burried in the ground under the tree canopy for support. The funnels leading to the bottles were placed over the rims of the tins so that the rims of the funnels were at a height of about 30 centimetres above the ground level. This minimized the effects of splash and turbulence.

Other possible problems associated with the measurement of throughfall apart from that of the sampling error are those of the drip effect. This error was suspected during the early stages of the readings referred to as 24 hour period, readings and this yielded exceptionally high values of throughfall. The reading time was then changed to immediately after a rain storm and reasonable results were obtained.

Stemflow

Points of measurement were chosen immediately below the major whorl of the trees because this is the point of maximum stemflow according to Hutchinson and Roberts (1981). The following were the major considerations taken in the constructi of the stemflow collectors; (i) Cost in relation to the area to be investigated (ii) ease of attachment to the tree and (iii) tightness of seal against the bole of the trees. The stemflow collectors used in this study were a modefication of those used by Aranda and Coutts(1963) and Likens and Brown (1970).

Polythene bags were wrapped around the tree trunks just below the main whorl and the joint between the bags and the tree surface was sealed by using rubber tubes which gave a reasobale water-tight fit. The water collected in these bags was then transfered to a measuring cylinder using rectangular pieces of foam which had been put in the collectors by way of squeezing and measured as stemflow. Squeezing water from the foam was one of the possible weakness in the method because some water probably was lost in wetting the foar itself and there was a possibility of not squeezing of all the water to the cylinder.

Interception Loss

Interception loss was derived directly from direct measurements of total precipitation, through . and stemflow as a residual from the formula:

Iri = P - Pg - Sf

whereIri is the total interception loss for the projected area of canopy (mm)

Pg is throughfall and Sf is stemflow

VEGETATION CHARACTERISTICS

Stand density

This was determined by using the sample plot- method which proved easier, less time consuming but reasonably accurate. A sample plot was chosen within the study compartment. The total number of trees in this plot was recorded after counting them. The total area of the sample plot was also measured. The total number of trees in the sample plot was divided by the total area of the plot. The answer obtained was taken as the average stand density for the whole study compartment.

The sample plot was quite representative in that it was taken from the middle of the compartment.

Other vegetation characteristics such as canopy form and leaf marphology were observed and described by the author. Information pertaining to the plantation history and maturity of trees was obtained from the Forestry Department staff and plantation book records.

DOCUMENTARY SOURCES

This included Library research on existing works done on similar studies. Information obtained included major findings and available methods concerning the data collection of the study.

MAPS

These were obtained mainly from the Geography Department of the University of Zambia, Lusaka 15 A_4 (1986) was the map sheet used to map out the study area.

DATA ANALYSIS

The data were analysed and Tabulated manually with the aim of presenting the data in form of short summaries. Tables correlation coefficients percentages of the total and diagrams were widely used.

C H A P T E R 5
RESULTS AND DISCUSSION

METEOROLOGICAL CONDITIONS

The total rainfall during the study period ranged from 2mm to 57 mm with an average of 19.4 mm. Rainfall intensity ranged from 2.2. to 80mm 1 hour. 24 hour runs of wind were used and wind speed was found to range from about 0.9m/1 sec up to as much as 2.9m/1 sec.

VEGETATIONAL CHARACTERISTICS

The trees were of Eucalyptus Grandis Species about 6 years old with traingular canopies. The main trunks were found to be about 1.0 metres from the ground surface to the main branching area. The trunks were smooth and about 0.19 metres in diameter.

INTERCEPTION COMPONENTS

Table 5.1 gives a summary of the results obtained for each gauge throughout the observation period for both readings taken immediately after the storm and 24 hour readings.

TABLE 5.1

Mean Percentage penetration, Stemflow and Interception loss for 24 hour readings (*) and those taken immediately after the stem

Gauge Number	No. of Observa-tion.	Mean Percentage Penetration (90)		Mean Stemflow (90)		Mean Intercept Loss (90)	
1	15	77	*96	16.6	*32	39	*42
2	15	72	*100	14.6	*31	41	*41
3	15	67	*93	14.5	*26	46	*47
4	15	68	*94	13.8	*30	44	*47
Grand Mean	15	71	*95.8	14.8	*29.8	42.5	*44.3

The table showsthat there are variations between the two sets of data, that is the readings taken immediately after the sterm and those taken on a 24 hour basis. There are variations too between samples. This variance is explained by factors associated with the nature of the vegetation and with the rainfall characteristics. These factors are in many ways interrelated and can be classfied as follows:

I. VEGETATIONAL CHARACTERISTICS

1. Plant species and maturity
2. Density of plant population
3. Wind effects

II. Rainfall Characteristics

1. Aggregate amount
2. Rainfall intensity

The influence of the above factors upon the results obtained in the study are considered below. But it should be borne im mind that the list is not exhaustive as many other factors may come into play. For instance the local topography and m meteorological condtions other than rainfall.

EFFECTS OF VEGETATIONAL CHARACTERISTICS

From Table 5.1 it is evident that the readings taken on a 24 hour basis recorded higher values for means of percentage penetration, stemflow and Interception loss. Mean percentage penetration for instance was a high as 100 percent for gauge no. 2 on the other hand 77 percent was the highest recorded percentage penetration for readings taken immediately after a sterm. The high values for percentage penetration can be attributed to dripping from the leaves and trickle along the branches of the trees. This is because even when the rain had ceased; water continued to drain from the canopy and the woody surfaces upt to about 24 hours later when the readings were taken. This rate of drip at any time, according to

Robins (1974) is assummed to be mainly dependent on the quantity of water on the canopy; so that the same rate of drip on two occassions seperated by a few hours indicates that there was the same quantity of water retained on the canopy at both times. Therefore, in a typical storm initially throughfall or pecerntage penetration is less than rainfall but becomes approximately equal to rainfall when the canopy is completely wetted. On the other hand readings taken immediately after a storm were low w except those rains that occurred during night time.

The mean percentage penetration recorded in the table shows similar general characteristics, for instance the 24 hour readings show a similar trend to those taken immediately after a storm except that each reading is about 20 to 28 mm higher.

Since the all the samples shown in the table were exposed to the same rainfall characteristics, it has been assumed that the differences in the readings recorded were due to the differences in the vegetational characteristics and positions of the sample trees within the stand in relation to wind effects.

EFFECTS OF RAINFALL CHARACTERISTICS

Table 5.2 shows the effects of rainfall characteristics on percentage penetration through the four samples for selected days.

Table 5.2

Effects of Rainfall Characteristics on Percentage Penetration Through the four samples on selected days

	DATE OF OBSERVATION	TOTAL RAINFALL MM	SAMPLE 1	2	3	4	REMARKS (PRECEDING OBSERVATI
1.	10/01/88	15.0	100	93	80	86	
2.	22/01/88	10.0	80	70	75	60	

TABLE 5.2 /CONT/....

	DATE OF OBSERVATION	TOTAL RAINFALL (MM)	SAMPLE 1	2	3	4	REMARK (Preceding Observati
3.	26/01/88	36.5	84	82	79	90	Last rain on 10/01/88 a sunny before this day
4.	27/01/88	53.5	93	74	65	65	
5.	28/01/88	15.5	83	77	70	77	
6.	11/02/88	14.0	71	57	64	78	
7.	15/02/88	14.5	62	68	82	41	
8.	17/02/88	9.0	66	72	55	77	
9.	19/02/88	32.0	86	70	73	68	
10.	4/03/88	29.0	70	68	68	72	
11.	7/03/88	57.0	71	70	67	68	Last rain was on 4/03/88. Dry for 3 days
12.	8/03/88	30.0	72	70	66	68	
13.	11/03/88	40.0	80	75	72	55	
14.	12/03/88	36.0	83	70	60	72	
15.	20/03/88	25.6	78	70	46	66	
16.	21/03/88	10.5	85	90	66	66	

During the study period there were no prolonged dry spells between rainfall occurrences although, there were a few short dry periods such as between 12th March and 20th March, 1988. Therefore the fluctuations in mean rainfall penetration recorded in Table 5.1 can be ascribed to rainfall factors such as aggregate amount, frequency and intensity.

Table 5.1 gives examples of the interactions between those factors. In some cases of the three factors had a greater effect while in another two of all three might interact. Therefore, in cases 2, 8 and 16 the low aggregates were obviously responsible for the low penetrations. Case 2 in particular was not affected appreciably by the longer preceding dry periods of about twelve days. If it were, the average penetration would have been lower than what was recorded. On the other hand the high penetration in case 4 was almost certainly due to high aggregates of rainfall and effects from the previous amount of rainfall which was appreciable. Case 5, 14 and 16 had high penetrations due to delayed dripping because the precding rain was fairly heavy.

Although penetrations for samples 1 and 2 in cases 4, 5 and 16 were high, those for samples 3 and 4 of the same cases were fairly low. This has been attributed to differences in canopy thickness and position of sample trees with respect to wind shelter effects as has already been mentioned earlier. Case 11 shows a fairly small penetration of very high aggregate rain falling on dry foliage. This is because when foliage is dry at the onset of rainfall most of the water is intercepted by the vegetation because vegetation storage capacity is large at this time.

<u>Aggregate Rainfall and Interception Loss</u>

The Relationship between aggregate rainfall and interception loss is illustrated in figure 5.1. The figure shows that the interception loss decreases as rainfall amount increases. This is because large amounts of rainfall are usually able to penetrate through the tree canopy than small amounts.

<u>Aggregate Rainfall and Throughfall</u>

The relationship between aggregate rainfall and percentage penetration or throughfall is illustrated in figure 5.2. It was found out that throughfall increases as aggregate rainfall increases. The figure indicates that this relationship is quite weak. The correlation coefficient is 0.35. This is becaus

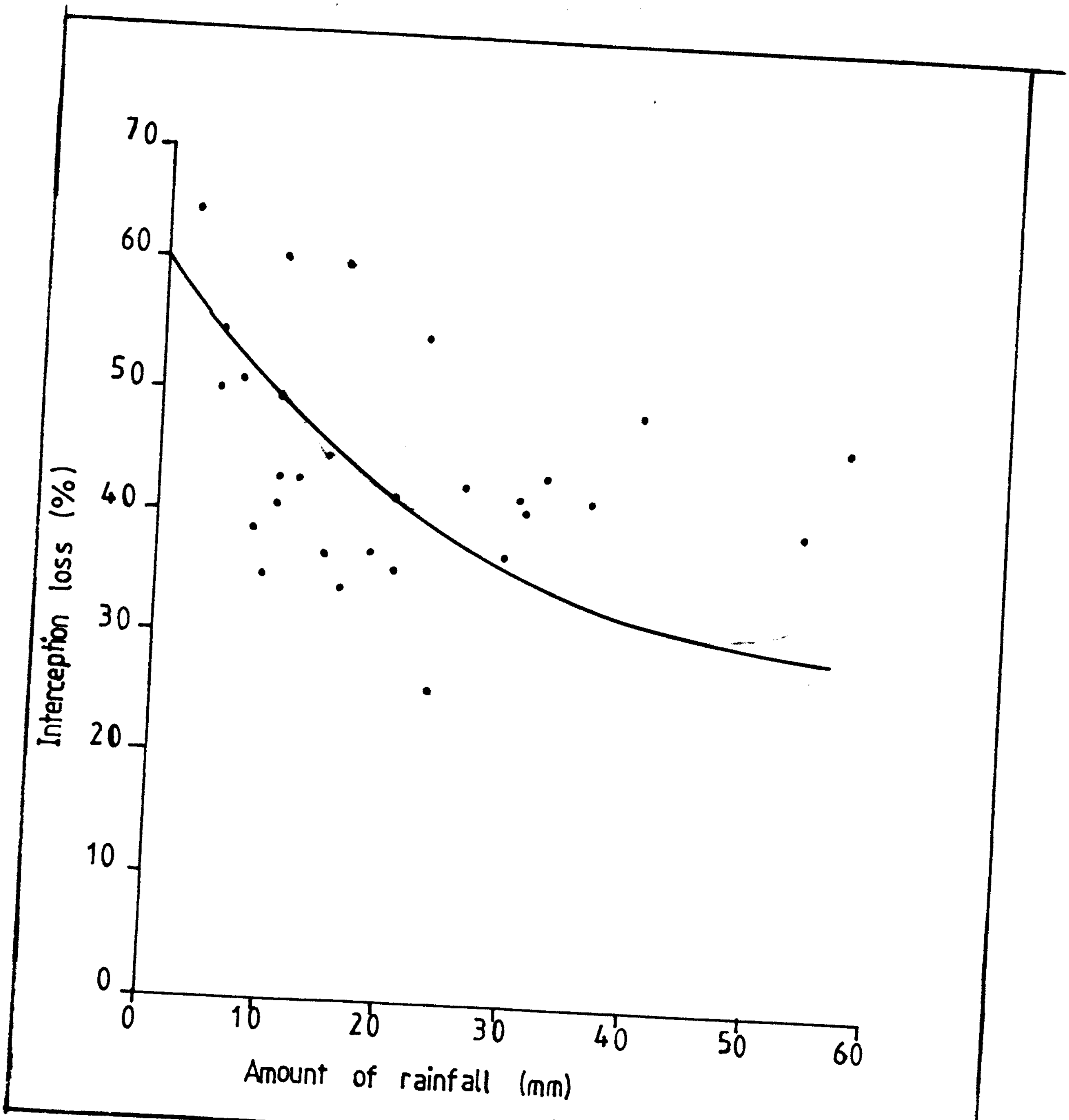

Fig. 5.1 Relationship between rainfall total and interception loss

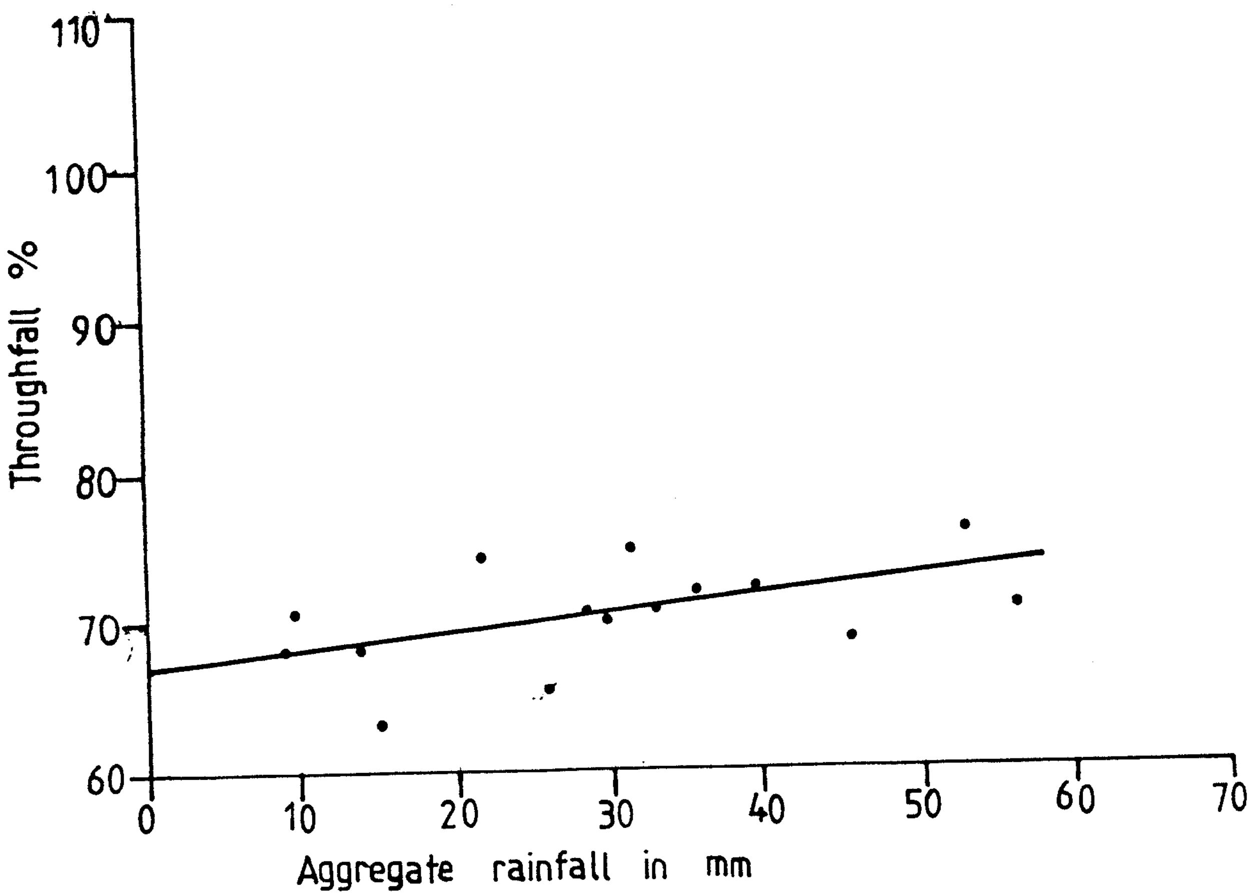

Fig. 5.2 Relationship between aggregate rainfall and throughfall

the trees in question are young with almost closed canopies.

Aggregate Rainfall and Stemflow

Figure 5.3 shows the relationship between aggregate rainfall and stemflow. The figure shows that there is a significant negative correlation between the two variables. The correlation coefficient is 0.5 indicating that stemflow decreases as aggregate rainfall increases. This perculiarity has been attributed to the fact that when rainfall amounts are large more water penetrates directly as throughfall and very little remains to trickle down the twigs, branches and finally down the main trunk as stemflow.

THE INFLUENCE OF RAINFALL INTENSITY

To find out the effects of rainfall intensity on interception loss a few selected observations were taken and the relationship obtained is shown in figure 5.4. The figure shows that there is a weak negative correlation between the two variables (r=-0.3 This means that interception loss decreases as rainfall intensity increases. This is because when rain falls with low intensity more water remains on the canopy surfaces and is lost back to the atmosphere as interception loss. However, this is influenced by the total rainfall as will be seen later.

Rainfall Intensity and Total Rainfall

To compare the effects of total amount and rainfall intensity, Four types of records were selected as defined in table 5.3. Rainfall intensity was grouped between that which ranged from 1-3 mm/hour and 4-5/hr. This cartered for variations in the intensity that may have occurred within the course of the storm.

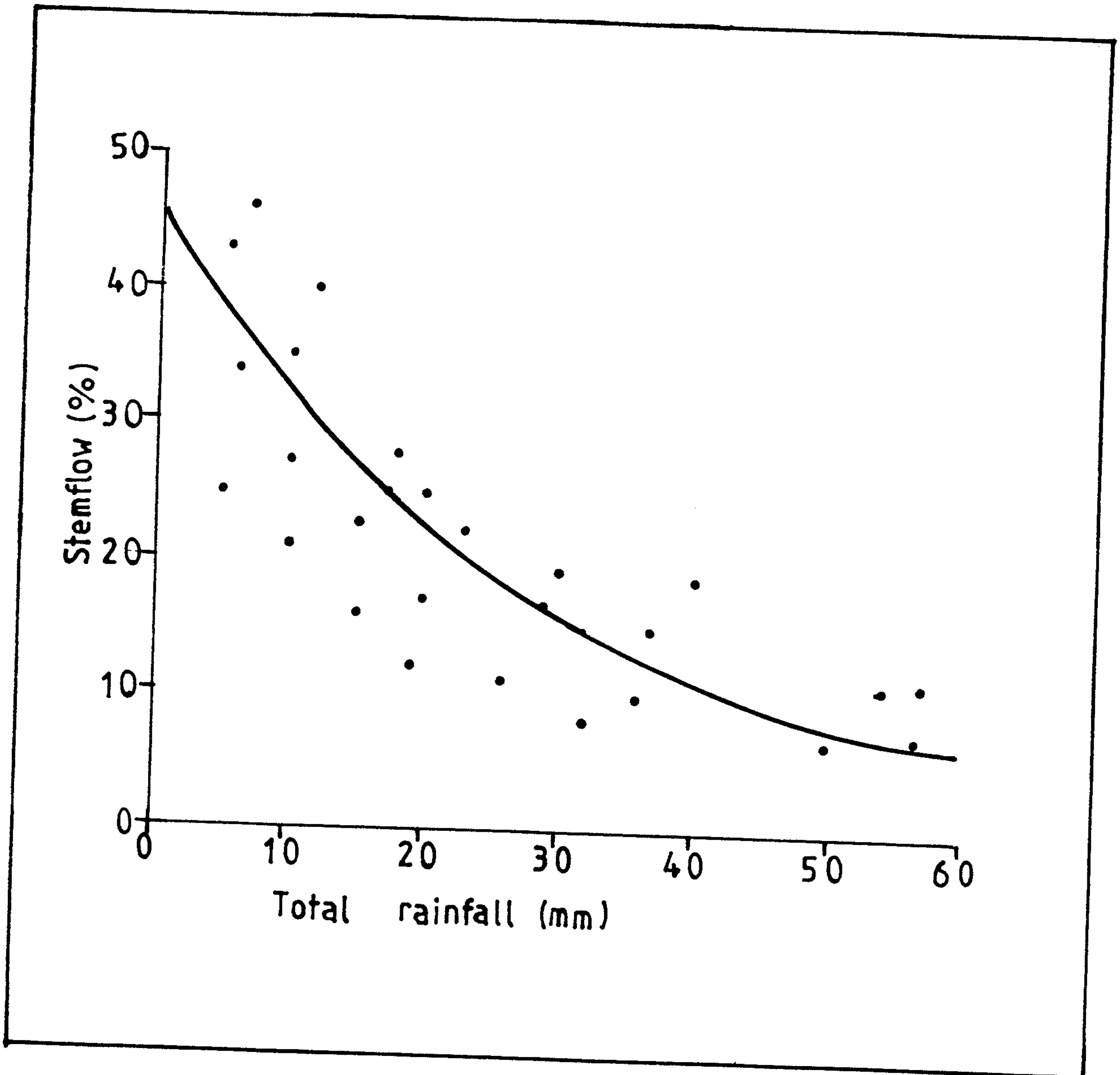

Fig. 5.3 Relationship between total rainfall and stemflow

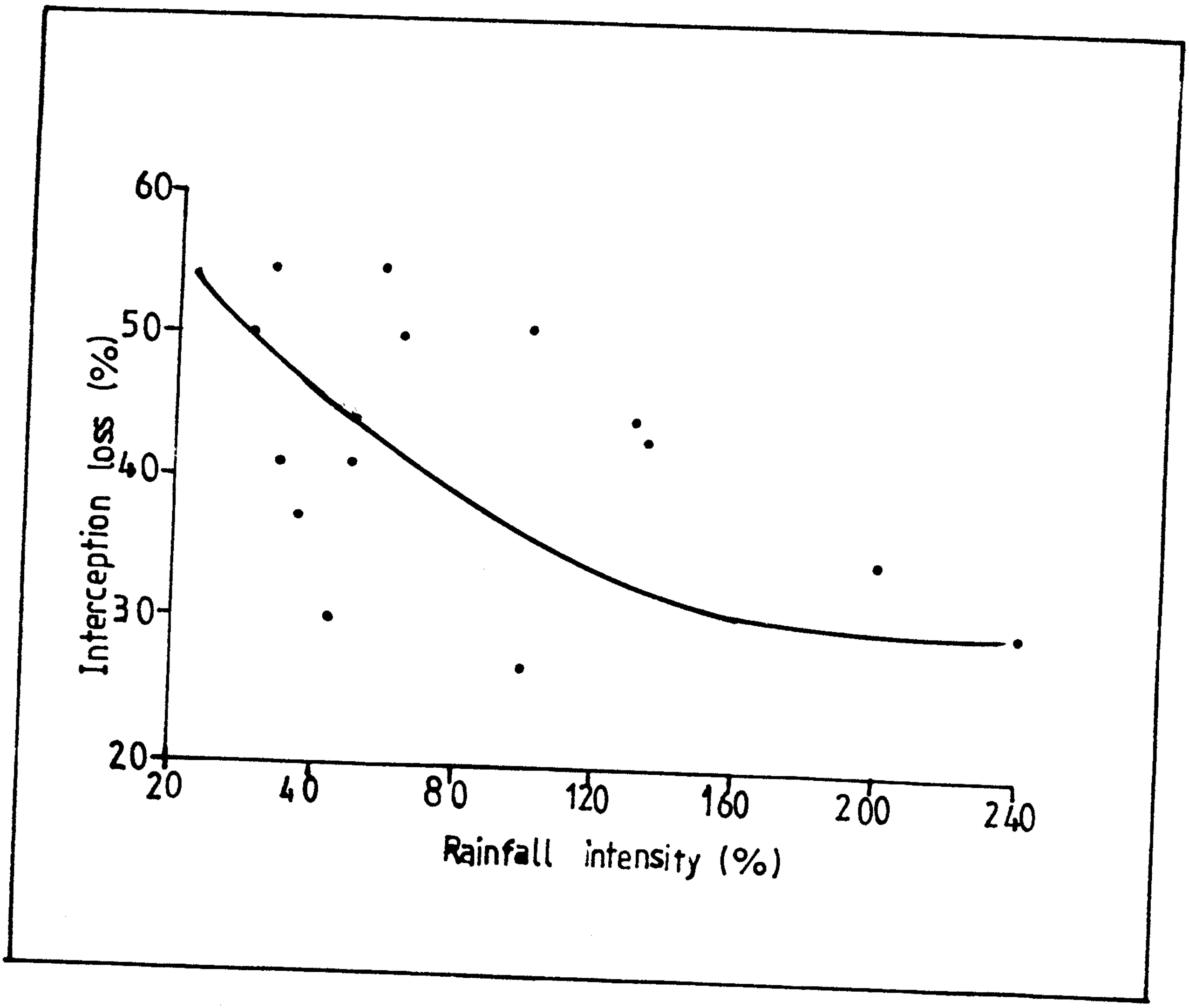

Fig. 5.4 Relationship between intensity and interception loss

TABLE 5.3

TYPE	A	B	C	D
Total rainfall (mm)	10	10	15	15
Intensity mm/hr	1-3	4-5	1-3	4-5

Results obtained for the four samples are shown in table 5.3

Table 5.4

Mean Percentage Penetration ($\bar{X}$) for Rainfalls of Different types at each gauge

Type of rainfall	Gauge Number			
	1	2	3	4
	$\bar{X}$	$\bar{X}$	$\bar{X}$	$\bar{X}$
A	38	48	29	35
B	64	60	37	55
C	65	53	44	77
D	75	70	63	67

From the table it is evident that penetration by rain of low intensity is increased by an increase in aggregate rainfall. This is illustrated well by rainfall type C for gauges 1 and 2. In these cases although rainfall intensity is low (between 1-3 mm/h) the increased aggregate rainfall of more than 15mm led to penetration of 65 and 53 percent. Penetration by rain of low amounts is increased by an increase in intensity as illustrated by rainfall type B for gauges 1 and 2. This also means that the penetration in a long term rainfall of small amounts is similar to that of a heavy storm of short duration.

Rainfall type D for all the gauges shows a high percentage penetration because both rainfall amounts and intensities are high.

STEMFLOW AND INTERCEPTION LOSS

The relationship between stemflow and interception loss has been illustrated in figure 5.5. Interception loss increases with stemflow.

PERCENTAGE PENETRATION AND INTERCEPTION LOSS

Figure 5.6 illustrates the relationship between percentage penetration and interception loss. The figure shows that interception loss decreases with an increase in percentage penetration. This is because when more water penetrates through the tree canopy very little is left on the surfaces to be evaporated back to the atmosphere as interception loss.

THRESHOLD VALUES

Threshold values are the minimum values of rainfall required before penetration through the canopy can occur. To find out these values a few selected observations were taken as shown in table 5.4. The zero values for rainfall penetration in the table indicate that there was no penetration until a certain minimum of rainfall was reached. This was found to be approximately 2.0mm. Thus the threshold value during the study period was 2.0mm.

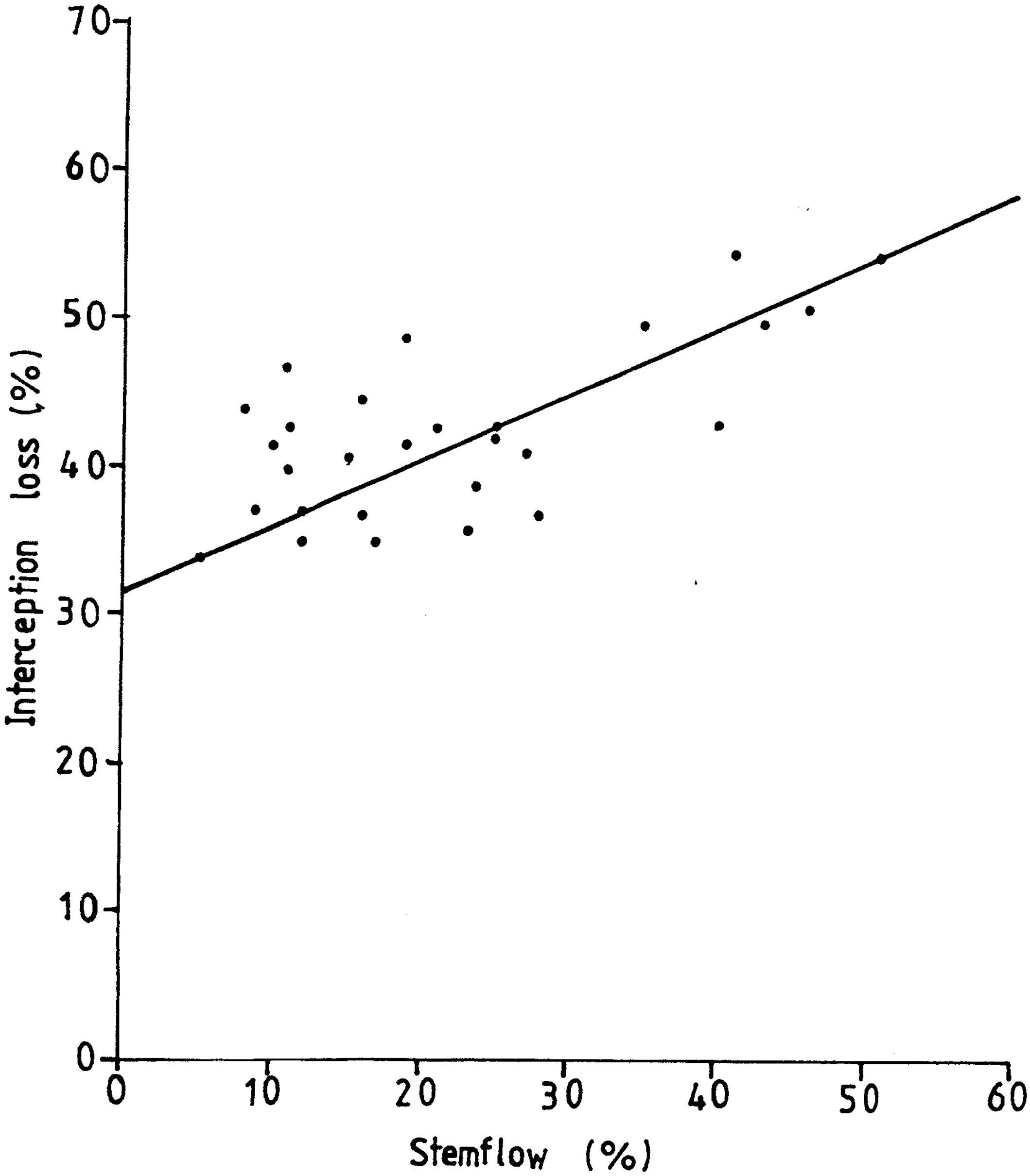

Fig. 5.5 Relationship between stemflow and interception loss

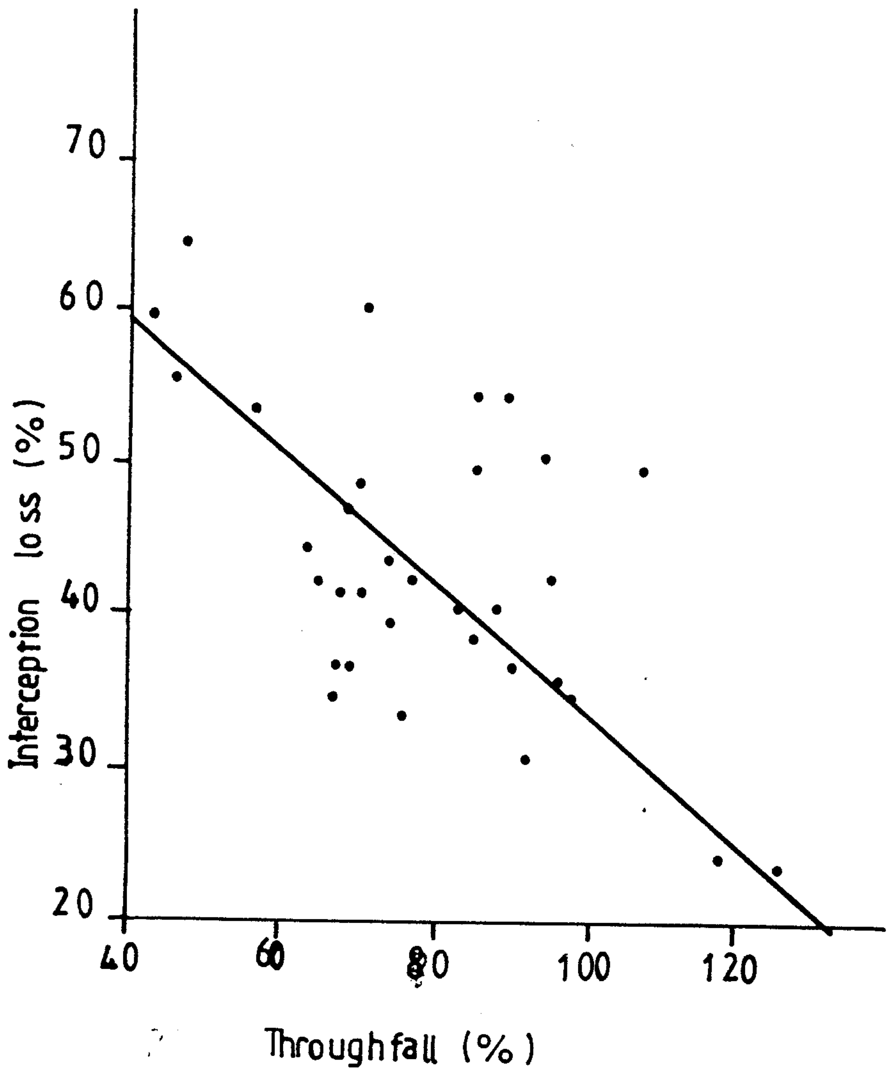

Fig. 5.6 Relationship between throughfall and interception loss

TABLE 5.5

Rainfall Penetration for Selected amounts of Rainfall

TOTAL RAINFALL (MM)	RAINFALL PENETRATION (MM)	PERCENTAGE PENETRATION
1.0	0.0	0.0
1.3	0.0	0.0
1.8	0.5	27.8
2.0	1.0	50.0

CHAPTER 6

CONCLUSION

Summary of Findings

The study found out that between 67 and 77 percent of the total in put of rainfall penetrated each of the tree canopies with the averager being 71 percent. The study also revealed that stemflow ranged from 13.5 to 16.6 percent with an average of 14.8 percent. Interception loss averaged42.5 and ranged from 39 to 46 percent. The study found out that before threshold value of 2mm of rainfall was received no penetration occured.

Conclusions

The study intended to verify two assumptions:- (a) vegetatio characteristics affect interception, (b) Rainfall characteristics affect interception.

To verify (a) required the examination of the vegetation characteristics and measurement of the interception components of stemflow, throughfall and interception loss in stands of varying stand density, species, age and consequently leaf marphology, structure and bark texture. But since this was not possible mainly due to lack of adequate time and also because the plantation was made up of only one species (Eucalyptus) it was decided that these components be measured under trees of one species and age and then make a comparison of results obtained with those that have been obtained by other studies conducted in various forest species and of different density and age.

A comparison of the results obtained from the study indicated that there is a relationship between vegetation characteristic and interception in many ways for instance the stemflow obtained(is mainly) in this study were higher than what most studies conducted in older plantations obtained. Therefore it was assumed that the age of the forest affects interception. In this case the distance travelled by the stemflow to the collector was short because the trees were young. Less water was thus absorbed by the bark or evaporated before it reached the collector and this increased the stemflow obtained. The bark of the trees were also smooth and this was found to have contributed to the high values of stemflow.

Throughfall estimates obtained in the study corresponded very closely with estimates other investigators have reported for coniferous forests such as Rogerson (1967) and Aranda and Coutts (1963). However, these estimates were found to be lower than most studies and this perculaiarity was attributed to the age of the trees under investigation. The trees were young and with very thick canopies which could have reduced penetration of rainfall.

Interception loss was therefore: found to be higherthan what most studies have recorded because of reduced throughfall and increased stemflow. The study therefore found out that vegetation characteristics had an effect on interception. The vegetation characteristics were not the only factors affecting interception and an attempt to verify assumption (b) was made. This required the examination of the rainfall characteristics over the area for a certain period of time and an examination of the interception components obtained under a particular type of rainfall. The main rainfall characteristics under consideration were aggregate amounts and intensity. The study revealed that aggregate amount of rainfall had an effect on interception in that as the amount increased interception loss decreased.

This was found to be a result of the fact that throughfall increased with rainfall amounts so that only very little water was intercepted by the tree canopy which later evaporated back to the atmosphere as interception loss.

It was also found that rainfall intensity had an effect on interception in that interception loss decreased with intensity This means that rainfalls of short duration but falling at high intensities penetrated the tree canopy more than that of low intensities and therefore very little water was lost to the atmosphere. The study revealed as was shown in chapter that rainfall intensity and total amount intract in their influence on interception. It was found out that penetration of rainfall of low intensity was increased by an increase in aggregate rainfall and low amounts were increased by an increase in intensity.

The study has revealed that both vegetation and rainfall characstics have an influence on interception and therefore any investigation of interception components in a forest either for water resource or soil conservation purposes requires consideration of these two major factors but it must be borne in mind that environmental and meteorological conditions of the area also play a part. The study revealed that interception loss constitutes an appreciable percentage of the total input of rainfall and this has implications in matters of water conservation. It is important to know how much a tree species intercepts rainfall before it is chosen as a species to be used in catchment area protections or soil protection if it has to replace indigenous species.

The investigation of the effects of vegetation and rainfall characteristics implied in this study could be either examined on a broad scale especially in major catchment areas. But more time should be taken so as to allow for a pilot study in order to allow for corrective measures. Investigation should also be intensified especially on the vegetation characteristics.

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